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EXPERIMENTAL INVESTIGATION OF PERFORMANCE AND EMISSION CHARACTERISTICS USING CHLORELLA ALGAE BIO DIESEL AS ALTERNATIVE FUEL

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ABSTRACT

Depleting sources of fossil fuels have raised an alarm for automobile engineers to search for an alternative fuel which can be provided to the society by ensuring its abundance availability and at an affordable cost. Simultaneously, use of fossil fuels have become a major contributor in producing green house gases affecting the environment adversely and increase in global warming is taking place which is very alarming for all geologists and environmentalists and has become detrimental for human existence on earth. Abundance availability of Chlorella vulgar is algae and the blends of the oil extracted from it through chemical process are used for the experiment to determine its suitability for use in automobiles as an alternative fuel.

KEYWORDS: Biodiesel, Specific Fuel Consumption, Brake Thermal Efficiency, Emissions & Mechanical Efficiency

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Original Article

INTRODUCTION

Setting up industries at a faster pace by continuous deforestation leads to increase of the temperature of earth day by day. If this increase in temperature is not stopped, the human existence on earth will become history due to melting of glaciers and submerging of the one third land part of earth which forms the basis of human life existence. Hence there is a need to find out a suitable alternative fuel which can be used in automobiles with reduced particulate and harmful exhaust gas emissions. Automobile engineers and other biologists are experimenting on various biomass and on blends of biodiesels for their suitability similar to the fossil fuels used at present. Bio oil is considered as the most preferred source of fuel due to its abundance availability and reduced cost of manufacturing. Chlorella vulgaris is one of the algae which is available in abundance and is a rich source of proteins [1][2][3]. The oil extracted from it can also be used as blends with diesel in different proportion in automobiles without significant lowering in mechanical and combustion properties. The algae oil has proved to be a better choice of substitute of diesel due to its better performance and scope for improvement in the properties using additives and even varying injection pressure [12][19][20][21]. The demand for renewable energy has made the scientific community to work day and night to identify and develop alternative fuel matching with the properties of fossil fuel like petrol, diesel etc. Many research works are carried out in this area and several combinations have been prescribed after testing of the fuel for

its mechanical and thermo-chemical properties [13][14][15][16][17][18]. The scientific community is in favour of utilization of renewable energy like energy produced through biomass and sources which can be constantly regenerated and sustainability of the source can be maintained [4][5][6][7][8][9][10][11].

ABOUT CHLORELLA MICROALGAE

Chlorella vulgaris is a green microalgae used as a dietary supplement and food additive mainly in Japan and is a rich source of proteins. The main producers of the microalgae are Germany, Taiwan and Japan. These microalgae is found to be a great source of biomass and is being seen as an alternative to shortage of fossil fuels due to its rich content of lipids, starch and proteins. If these microalgae are grown in favorable conditions and with different techniques, its protein content is increased to high level. The biomass is harvested by centrifugation process. In comparison to soya bean, corn and rape seed, the biomass obtained from these algae is found to be a good source of bio energy due to its high productivity and less competitive with the food production. The starch present in the microalgae is a rich source of bioethanol and the lipids present can be a source of biodiesel production. Smell like fish is the main factor for not using it in several food products and also due to its dark colour. It is also used for medical treatment especially in Japan.

CHEMICAL PROPERTIES OF CHLORELLA MICROALGAE OIL

The Biodiesel produced from Chlorella vulgaris microalgae as shown in Figure 1 is tested for its combustion properties before its use in actual internal combustion engine to determine its performance and emission characteristics. The properties tested in lab are given in table 1.

Figure 1: Biodiesel Produced from Chlorella Vulgaris Microalgae.

Table 1: Properties of Biodiesel Produced from Chlorella Vulgaris Microalgae

Sl. No.	Description	Values
1.	Nature of Sample	Biodiesel – ALG B100
2.	Quantity of Sample	300 ml
3.	Kinematic Viscosity @ 40^{0}C in cSt (Centistokes)	4.07
4.	Flash Point in ^{0}C	108^0
5.	Fire Point in ^{0}C	119^0
6.	Gross Calorific Value in kj/kg	39321.21
7.	Density in kg/m^3	896

EXPERIMENTAL SET UP

The internal combustion engine set up utilized for the test is Kirloskar TV1 Variable Compression Ratio (VCR) Engine and as shown in Figure 2. This engine is a one cylinder Four stroke, Constant Speed, Water Cooled Diesel Engine. The details of the engine specifications and mechanical parameters are given in table 2.

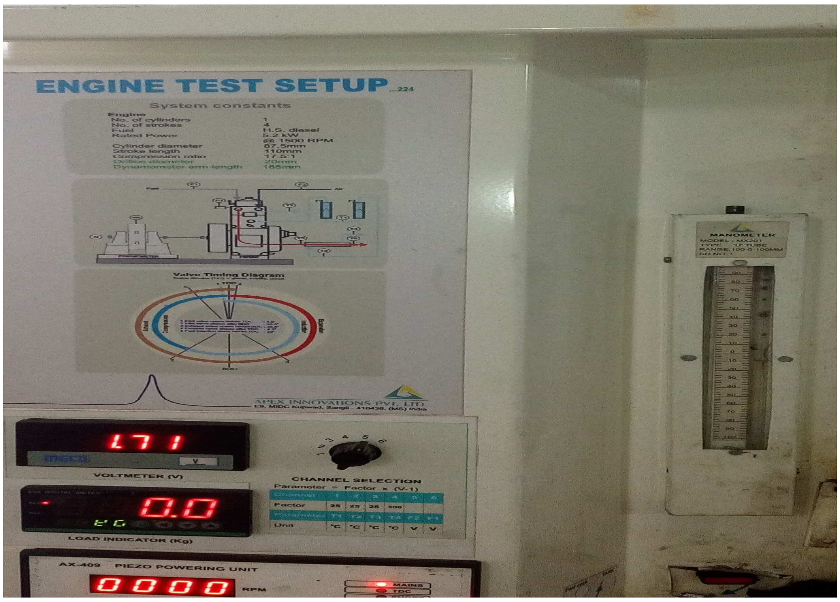

Figure 2: Kirloskar Engine Test Set up.

Table 2: Details of the Kirloskar Engine Used for the Test

Sl. No.	Description	Values
1.	Cylinder Bore in mm	87.50
2.	Stroke Length in mm	110.00
3.	Connecting Rod length in mm	234.00
4.	Swept volume (cubic centimeter)	661.45
5.	Compression Ratio	17.50
6.	Power in kW @ 1500 RPM	5.20

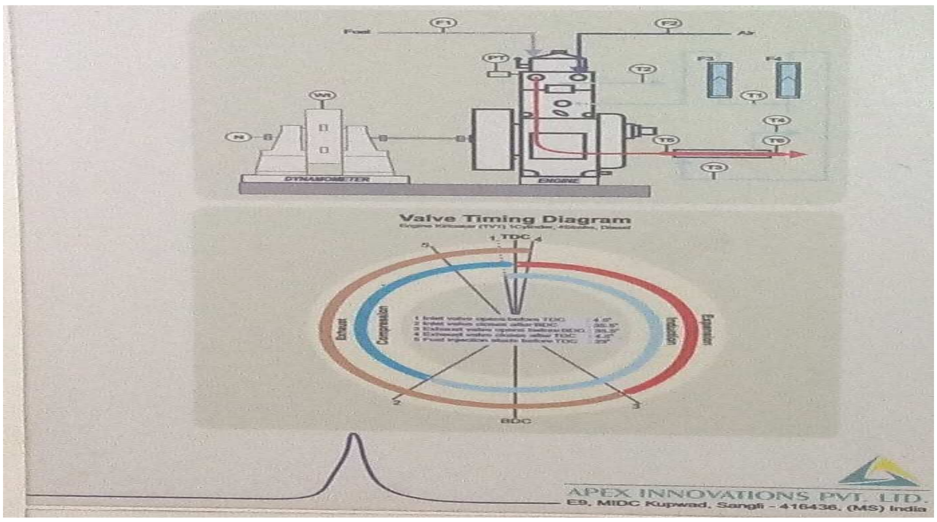

Figure 3: Engine Test Set up with valve Timing Diagram.

RESULTS, COMPARATIVE ANALYSIS AND DISCUSSIONS ON MECHANICAL PERFORMANCE OF B100, B40, B20 BLENDS OF BIO DIESEL AND PURE DIESEL AT DIFFERENT LOADING CONDITIONS FOR BEST BLEND

Two Blends of bio oil B40 (40% bio oil + 60% Diesel) and B20 (20% bio oil + 80% Diesel) extracted from Chlorella vulgaris microalgae are obtained by mixing bio fuel and pure diesel in proportion.

In order to find out the best blend, pure bio oil B100 (100% bio oil), Pure diesel (100% Diesel) and blends of biodiesel are tested for their mechanical performance and combustion properties. They are also tested for their emission characteristics. The test data collected are analyzed to select the best blend.

The performance parameters for which test results evaluated and analyzed are discussed in detail.

Brake Mean Effective Pressure (BMEP)

Mean effective pressure is the useful parameter used to calculate work transfer from the gas to the piston in a reciprocating engine. Indicated Mean effective pressure is the gross work transferred to the piston whereas Brake Mean effective pressure is the actual work transferred to the piston and is converted into useful work. The difference of IMEP and BMEP will be loss of work and need to be minimized. The BMEP values obtained are given in table 3 and the graph plotted is shown in Figure 4.

Table 3: Test Data – Brake Mean Effective Pressures in Bar at Different Loads

Load/Fuel	B20	B40	B100	Diesel
0	0.03	0.03	0.03	0.03
25	1.58	1.56	1.53	1.59
50	3.13	3.1	3.08	3.14
75	4.67	4.64	4.59	4.69
100	6.25	6.2	6.16	6.27

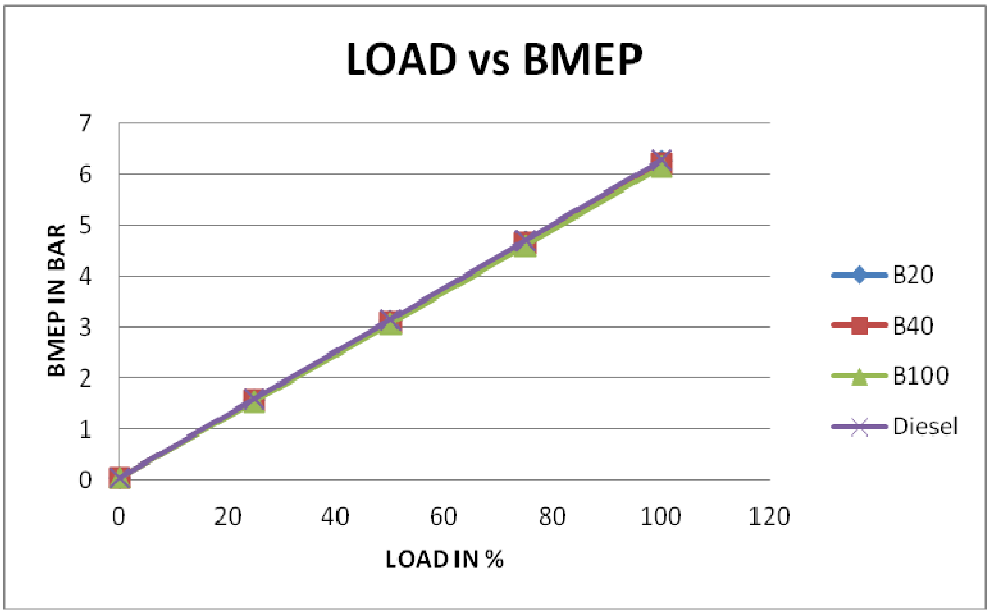

Figure 4: A comparative Analysis of BMEP for values Obtained for Blends of Algae Oil and Pure Diesel (X - Axis Load in % and Y –Axis MEP in Bar).

Discussion

During analysis of the values obtained for Brake Mean Effective Pressure (BMEP), biodiesel B-20 seems to be the best blend as its BMEP value are almost very closer to the values of BMEP in pure diesel at all ranges of load.

The reason for lower BMEP in blends of biodiesel is due to improper atomization due to little high viscosity. The same can be improved further by addition of suitable additives and also by varying injection pressure.

Brake Power

Whenever any engine is running with any type of fuel, power is produced. The total power produced by the engine and matching with the theoretical value is called Indicated Horse Power (IHP) and the power actually available for doing useful work is called Brake Horse Power (BHP). The difference of indicated and brake horse power is called Friction Horse Power (FHP) and is considered as loss. The effort of an engineer is to reduce the loss to very minimum in order to increase the efficiency of the engine. The values obtained are given in table 4 and the graph plotted is shown in Figure 5.

Table 4: Test Data – Brake Power in kW at Different Loads

Load/Fuel	B20	B40	B100	Diesel
0	0.02	0.01	0.01	0.02
25	1.3	1.28	1.25	1.32
50	2.55	2.53	2.45	2.58
75	3.75	3.72	3.68	3.76
100	4.94	4.89	4.81	4.96

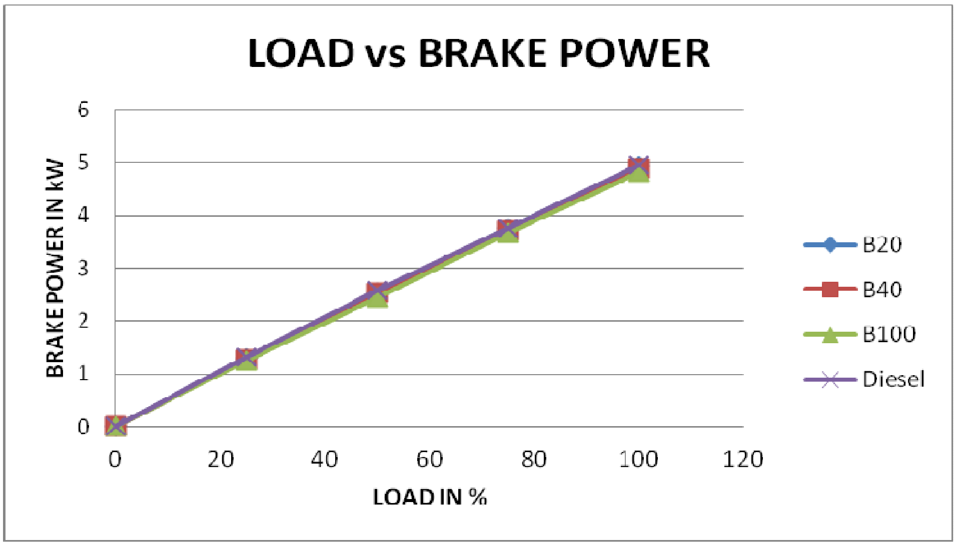

Figure 5: A Comparative Analysis of Brake Power Values obtained for Blends of Algae Oil and Pure Diesel (X - Axis Load in % and Y –Axis Brake Power in Kilo Watt).

Discussion

At all ranges of loading conditions, bio diesel B20 has emerged as best blend and a suitable substitute as the test values obtained are closer to the brake power produced with pure diesel.

The reason for slightly less brake power obtained with blends of Bio diesel is due to incomplete combustion of fuel and air mixture. The same can be improved further by providing proper atomization and by varying injection pressure.

Brake Thermal Efficiency

Brake thermal efficiency provides the information on efficiency of conversion of heat energy of fuel to break power. This information is very useful in determining the suitability of fuel for a particular application. In an engine during combustion of fuel, the engine produces indicated power which is more or less theoretical value calculated with specified mathematical expression and depends on the calorific value of fuel. The efficiency related to indicated power is called Indicated Thermal Efficiency and efficiency related to break power is called Brake Thermal Efficiency. The values obtained are given in table 5 and the graph plotted is shown in Figure 6.

Table 5: Test Data – Brake Thermal Efficiency in % at Different Loads

Load/Fuel	B20	B40	B100	Diesel
0	0.63	0.62	0.59	0.65
25	18.67	17.32	16.01	18.73
50	25.7	24.51	21.89	27.39
75	29.03	28.93	25.58	30.49
100	31.09	30.05	27.05	32.46

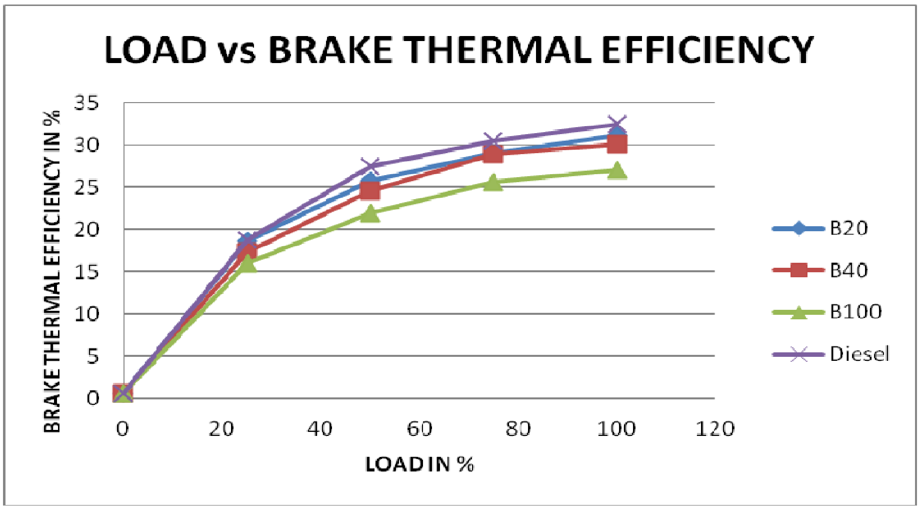

Figure 6: A Comparative Analysis of Brake Thermal Efficiency Values Obtained for Blends of Algae Oil and Pure Diesel (X - Axis Load in % and Y – Axis Brake Thermal Efficiency in %).

Discussion

On analysis of the test data obtained, biodiesel B20 has proved to be the best blend as the brake thermal efficiency values are closer to the brake thermal efficiency values with pure diesel.

The reason for lower thermal efficiency is due to incomplete combustion which can be improved further by adding 10% suitable additives like ethylene glycol.

Specific Fuel Consumption (SFC)

Fuel consumption is the quantity of fuel consumed by the engine per unit time to produce power and is expressed in kg / hr. When this fuel consumption is expressed in terms of per unit power produced by the engine, it is known as Specific Fuel Consumption (SFC) and is expressed in kg/kwh. The values obtained are given in table 6 and the graph plotted is shown in Figure 7.

Table 6: Test Data – Specific Fuel Consumption in kg/kwh at Different Loads

Load/Fuel	B20	B40	B100	Diesel
0	13.7	14.19	15.03	14.68
25	0.46	0.5	0.57	0.45
50	0.33	0.36	0.42	0.31
75	0.32	0.34	0.36	0.28
100	0.28	0.29	0.34	0.26

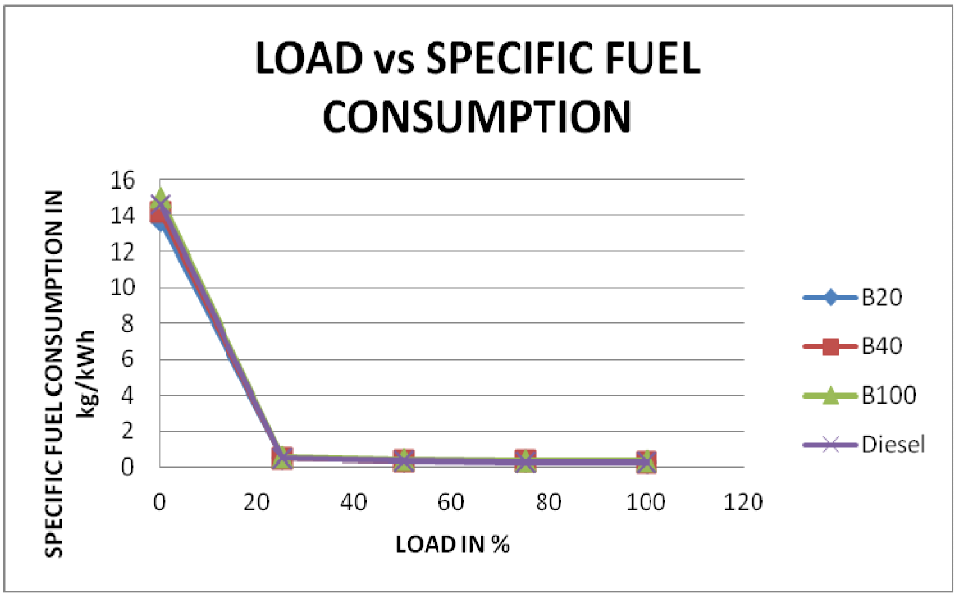

Figure 7: A Comparative Analysis of Specific Fuel Consumption values Obtained for Blends of Algae Oil and Pure Diesel (X - Axis Load in % and Y –Axis Specific Fuel Consumption in kg/kwh).

Discussion

On analysis of the data obtained, except at 0% load, SFCs of B-20 and other blends are more than the respective values with pure diesel.

The increase in fuel consumption is due to insufficient atomization leading to incomplete combustion and further loss of unburned fuel. The viscosity of biodiesel can be lowered for proper atomization by adding suitable additives.

Mechanical Efficiency

Mechanical efficiency is the indication of efficient working of all parts and components of an engine. It shows that the effectiveness of the engine in conversion of input energy to output energy. The values obtained are given in table 7 and the graph plotted is shown in Figure 8.

Table 7: Test Data – Mechanical Efficiency in % at Different Loads

Load/Fuel	B20	B40	B100	Diesel
0	1.07	1.04	0.75	1.09
25	34.51	33.58	31.17	35.52
50	51.96	51.69	48.49	52.49
75	63.66	62.98	60.35	64.41
100	71.18	70.38	68.28	71.78

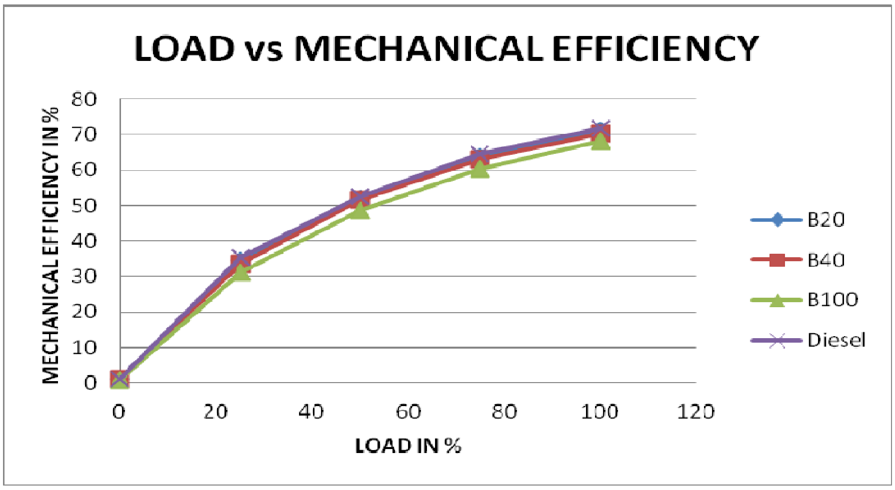

Figure 8: A Comparative Analysis of Mechanical Efficiency Values Obtained For Blends of Algae Oil and Pure Diesel (X - Axis Load in % and Y –Axis Mechanical Efficiency in %).

Discussion

The mechanical efficiency of the blends have decreased in comparison to the values obtained for pure diesel but B20 blend can be considered as the 2nd choice for alternate fuel with similar efficiency as diesel.

The lowering of the efficiency is due to insufficient atomization and incomplete combustion due to high viscosity of bio diesel. The efficiency can be improved by lowering the viscosity and having proper atomization leading to complete combustion.

RESULTS, COMPARATIVE ANALYSIS AND DISCUSSIONS ON EXHAUST GAS EMISSIONS OF B100, B40, B20 BLENDS OF BIO DIESEL AND PURE DIESEL AT DIFFERENT LOADING CONDITIONS FOR BEST BLEND

The blends (B20, B40), pure Biodiesel (B100) and Pure Diesel are tested for their emission characteristics. The analysis of emissions of Carbon Monoxide (CO) in %, Carbon Dioxide (CO_2) in %, Oxygen (O2) in %, Hydro Carbon (HC) in ppm and Nitrogen Oxides (NO_X) in ppm is done for each blend and at different loading conditions i.e. 0%, 25%, 50%, 75% and 100%.

Emission of Carbon Monoxide (CO)

The blends B20, B40, B100 and Pure Diesel are tested for its emission characteristics of Carbon Monoxide (CO) at different loading conditions. The data obtained are mentioned in table 8 and the graph is plotted in Figure 9.

Table 8: Test Data – Emission of Carbon Monoxide (CO) in % at Different Loads by Blends of Biodiesel and Pure Diesel

Load/ Emissions	B20	B40	B100	Diesel
0	0.049	0.052	0.083	0.029
25	0.044	0.048	0.058	0.037
50	0.04	0.045	0.057	0.024
75	0.037	0.048	0.064	0.031
100	0.185	0.186	0.261	0.181

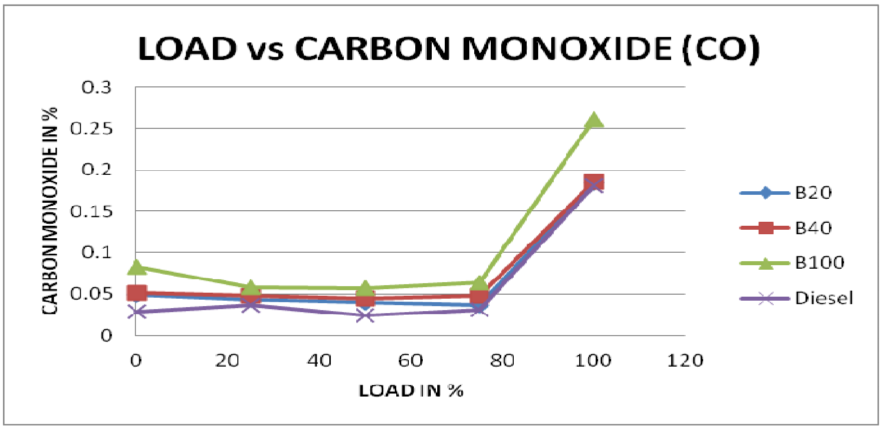

Figure 9: A Comparative Analysis of Emission of Carbon Monoxide (CO) in % at Different Loads by Blends of Biodiesel and Pure Diesel (X - Axis Load in % and Y –axis Carbon Monoxide (CO) in %).

Discussion

The emissions of Carbon Monoxide are slightly higher for all blends than pure diesel. Performance of B20 blend is comparatively better in comparison at all loading conditions.

The reason for higher emissions is due to high carbon content and incomplete combustion of the biodiesel. Complete combustion can be achieved by adding suitable additives and this will lead to improvement in performance.

Emission of Carbon Dioxide (CO_2)

The blends B20, B40, B100 and Pure Diesel are tested for its emission characteristics of Carbon Dioxide (CO_2) at different loading conditions. The data obtained are mentioned in table 9 and the graph is plotted in Figure 10.

Table 9: Test Data – Emission of Carbon Dioxide (CO2) in % at Different Loads by Blends of Biodiesel and Pure Diesel

Load / Emissions	B20	B40	B100	Diesel
0	1.81	1.86	2.04	1.78
25	3.83	3.91	4.01	3.91
50	5.95	6.1	7.85	5.92
75	7.76	7.91	8.72	7.42
100	9.62	9.93	10.1	9.52

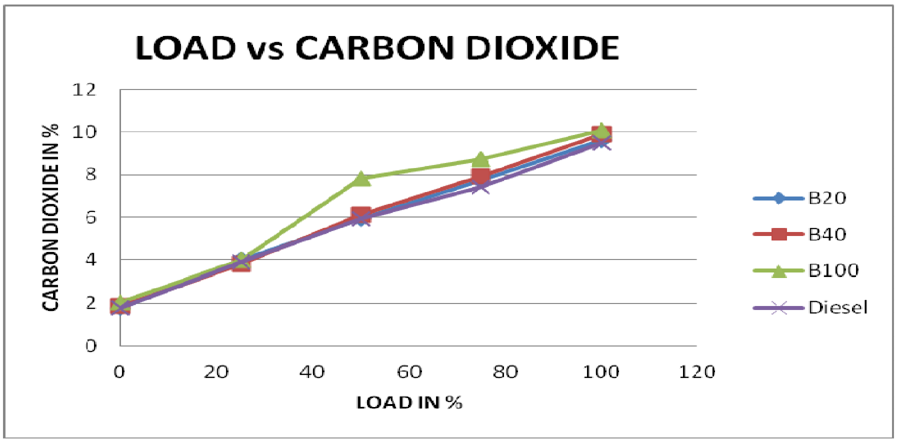

Figure 10: A Comparative Analysis of Emission of Carbon Dioxide (CO_2) in % at Different Loads by Blends of Biodiesel and Pure Diesel (X - Axis Load in % and Y –Axis Carbon Dioxide (CO_2) in %).

Discussion

The emissions of Carbon Dioxide (CO_2) are slightly higher for blends than pure diesel. Performance of B20 blend is comparatively similar to the diesel and can be considered as a suitable substitute for the diesel.

The reason for higher emission of CO_2 in biodiesel is due to higher viscosity and incomplete combustion of biodiesel. Emission of CO_2 can be lowered by employing suitable catalytic converters and means to attain complete combustion in cylinder.

Emission of Oxygen (O_2)

The blends B20, B40, B100 and Pure Diesel are tested for its emission characteristics of oxygen (O_2) at different loading conditions. The data obtained are mentioned in table 10 and the graph is plotted in Figure 11.

Table 10: Test Data – Emission of Oxygen (O2) in % at Different Loads by Blends of Biodiesel and Pure Diesel

Load / Emissions	B20	B40	B100	Diesel
0	18.31	18.25	18.14	18.36
25	15.18	15.15	14.42	15.33
50	12.55	12.38	11.86	12.64
75	9.89	9.28	8.3	9.96
100	6.89	6.86	6.4	6.94

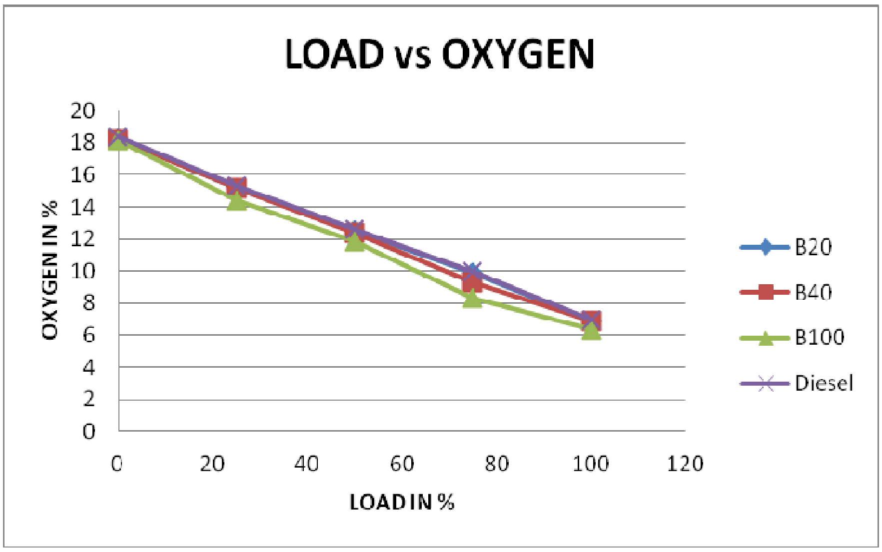

Figure 11: A Comparative Analysis of Emission of Oxygen (O_2) in % at Different Loads by Blends of Biodiesel and Pure Diesel (X - Axis Load in % and Y –Axis Oxygen (O_2) in %).

Discussion

The emission of oxygen (O_2) is lesser for all blends than pure diesel. Performance with respect to emission of oxygen of B20 blend is comparatively closer to the values with diesel and can be considered as a suitable substitute for the diesel.

The reason for lowering of emission of oxygen is due to requirement of more oxygen for combustion of blends of biodiesel. Comparatively more oxygen is needed for forming chemically correct mixture for having a complete combustion.

Emission of Hydrocarbons (HC)

The blends B20, B40, B100 and Pure Diesel are tested for its emission characteristics of hydrocarbons (HC) in PPM (parts per million) at different loading conditions. The hydrocarbons are the primary source of energy in fuel and its emission indicates unused fuel and incomplete combustion. The emitted hydrocarbons combine with sunlight and nitrogen to form ozone which poses threat to the environment. The data obtained are mentioned in table 11 and the graph is plotted in Figure 12.

Table 11: Test Data – Emission of Hydrocarbons (HC) in PPM at Different Loads by Blends of Biodiesel and Pure Diesel

Load/ Emissions	B20	B40	B100	Diesel
0	9	12	21	8
25	19	22	25	17
50	24	25	30	25
75	31	33	40	34
100	52	54	61	54

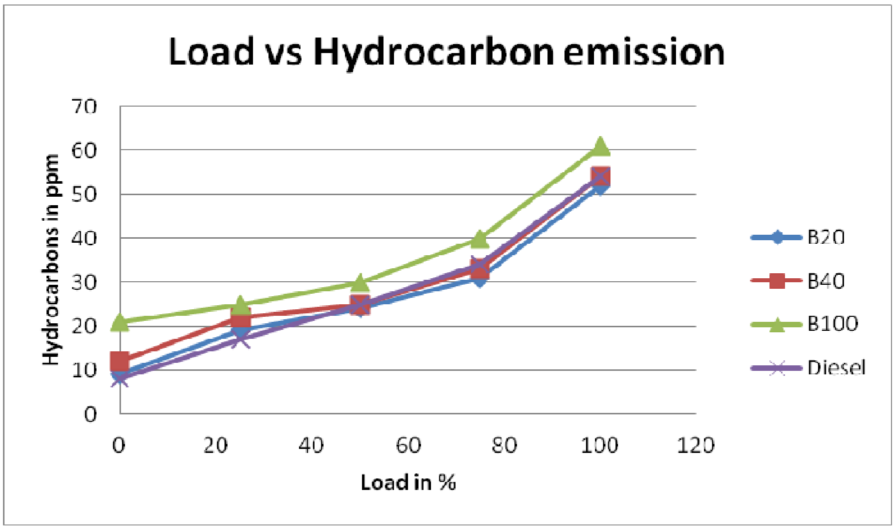

Figure 12: A Comparative Analysis of Emission of Hydrocarbons (HC) in PPM at Different Loads by Blends of Biodiesel and Pure Diesel (X - Axis Load in % and Y –Axis Oxygen (O_2) in %).

Discussion

The emissions of Hydrocarbons (HC) which are the source of energy in fuel are found to be lesser in case of B20 blend in comparison to all other blends. At 0% and 25% load, B20 blend produced emission of HC slightly more than pure diesel but above 25% load, B20 blend produced lower emission of HC than pure diesel.

At higher loads, the emission of hydrocarbons has reduced almost in all blends which indicate utilization of maximum available fuel by the engine for producing power.

Emission of Nitrogen Oxides (NO_X)

The blends B20, B40, B100 and Pure Diesel are tested for its emission characteristics of Nitrogen Oxides (NO_x) in PPM (parts per million) at different loading conditions. NO_x includes nitric oxide (NO) and Nitrogen dioxides (NO_2) and even other oxides also. The data obtained are mentioned in table 12 and the graph is plotted in Figure 13.

Table 12: Test Data – Emission of Nitrogen Oxides (NOx) in PPM at Different Loads by Blends of Biodiesel and Pure Diesel

Load / Emissions	B20	B40	B100	Diesel
0	67	62	53	94
25	458	435	431	462
50	833	822	801	849
75	1184	1161	1118	1203
100	1394	1380	1371	1421

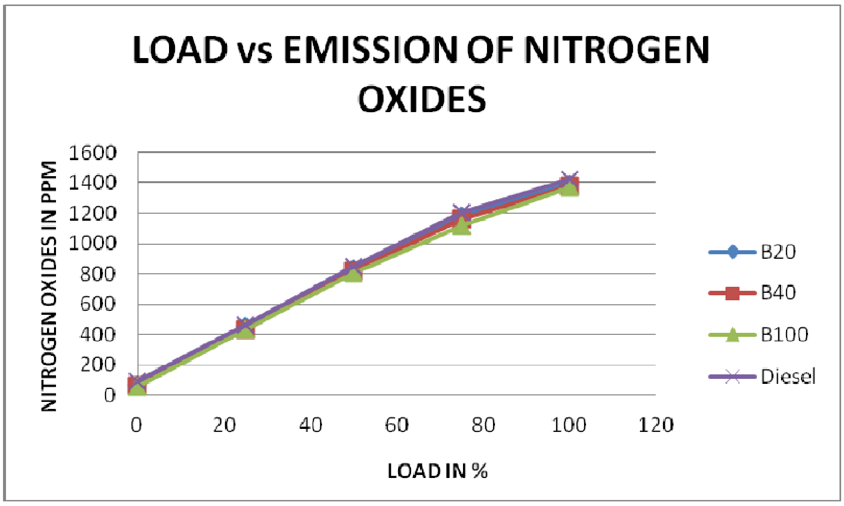

Figure 13: A Comparative Analysis of Emission of Nitrogen Oxides (NOx) in PPM at Different Loads by Blends of Biodiesel and Pure Diesel (X - Axis Load in % and Y –Axis Oxygen (O_2) in %).

Discussion

The emissions of Nitrogen Oxides (NOx) are considerably lower in all blends of the bio diesel. Performance of B20 Blend in comparison to pure diesel is better and can be considered as a suitable substitute for the diesel.

The lower emissions of NOx with respect to blends of bio diesel are due to its inherent increased content of oxygen which makes it to utilize less atmospheric air for their combustion. The main source of NOx is utilization of atmospheric air for combustion due to availability of oxygen along with high amount of nitrogen content in it which is exhausted out in its original form as nitrogen do not participate in combustion process.

CONCLUSIONS

The blends of microalgae fuel i.e. B20, B40, B100 are tested in a Kirloskar Variable Compression Ratio Diesel engine for their performance with respect to mechanical properties like Mean Effective Pressures, Brake Power, Specific Fuel Consumption, Thermal Efficiency and Mechanical Efficiency at 0%, 25%, 50%, 75% and 100% loading conditions. The blends are also tested for their emissions with respect to Carbon Monoxide (CO), Carbon Dioxide (CO_2), Oxygen (O_2), Hydrocarbons (HC) and Nitrogen Oxides (NOx) using 5 gas analyzer. The data obtained are compared with the data obtained by testing pure diesel for the above mentioned properties and also for emissions. Overall, it is found that the B20 can become a good substitute of diesel in future as with similarity in all other mechanical properties and having closer values which can be improved further by using additives, it has considerably lower emissions of Carbon Dioxide (CO_2), Hydrocarbons (HC) and Nitrogen Oxides (NOx) whose concentrations have reached to an alarming and dangerous level in

the present atmosphere and is also contributing for Global warming. The need of the hour is to arrest this trend of increasing pollution and substitute an eco-friendly bio fuel which can also solve the problem of crisis and depleting level of fossil fuels.

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REFERENCES

1. *B. Yang and J. Liu, Chlorella Species as Hosts for Genetic Engineering and Expression of Hetrologous Proteins: Progress, Challenge and Perspective, Biotechnol., 11 (2016).*
2. *V Naresh and S Prabhakar, Performance and Emission Characteristics of Algae Oil on VCR Diesel Engine, Journal of Chemical and Pharmaceutical Research, 2018, 10(4).*
3. *S. Sarpal, C. R. Ingrid et al., Investigation of Biodiesel Potential of Biomass of Microalgaes Chlorella, Spirulina and Tetraselmis by NMR and GC-MS Techniques, J. Biotechnol., 6, 1 (2016).*
4. *Azadi, P., et al. 2014. "The carbon footprint and non-renewable energy demand of algae-derived biodiesel." Applied Energy 113:1632 – 44. doi: 10.1016 /j.apenergy. 2013.09.027.*
5. *Y. P. Nagaraj et al., Production of Biofuel by using Micro Algae, Int. J. Curr. Microbiol. App. Sci., 3(4) (2014).*
6. *Algae for Bio Fuel Production, Farm Energy, January 31 (2014).*
7. *Benemann, J. R., R. P. Goebel, J. C. Weissman, and D. C. Augenstein. 1982. Microalgae as a source of liquid fuels. Final techni¬cal report. (No. DOE/ER/30014-T1). EnBio, Inc.: Fairfield, CA.*
8. *Rao, P. V., & Rao, B. A. (2018). Heat release rate, performance and vibration analysis of diesel engine operating with biodiesel-Triacetin additive blend fuels. International Journal of Automobile Engineering Research and Development, 8(2), 1-12.*
9. *Jale Yanik, Ralph Stahl, Nicole Troeger and Ali Sinag, Pyrolysis of Algal Biomass, J. Anal. Appl. Pyrolysis, 103, 134-141 (2013).*
10. *K. Chaiwong et al., Study of Biofuel and Biochar Production from Algae by Slow Pyrolysis, Biomass and Bioenergy, 56, 600-606 (2013).*
11. *Collet, P., L. Lardon, A. Hélias, S. Bricout, I. Lombaert-Valot, B. Perrier, and O. Bernard. 2014. "Biodiesel from microalgae–Life cycle assessment and recommendations for potential improvements." Renewable Energy 71: 525–33. doi:10.1016/j. renene.2014.06.009.*
12. *S. P. Anne, E. Harman-Wave et al., Micro Algae as a Renewable Fuel Source-Fast Pyrolysis of Scenedesmes, Renew. Energy, 60, 625-632 (2013).*
13. *R. Velappan, S. Sivaprakasam and M. Kannan, Study the Performance of Algae Oil in Diesel Engine with Varios Injection Pressure, IRJET, 2(5) (2015).*
14. *Sriram, V., JEYAJEEVAHAN, G., BRITTOJOSEPH, G., & DURAIRAJ, R. (2017). Engine Performance and Emission Characteristics of 1-Octanol Blended Bio-diesel in a Single Cylinder Diesel Engine. Stroke, 2000, 110.*
15. *Mata, T. M., A. A. Martins, and N. S. Caetano. 2010. "Microalgae for biodiesel production and other applications: a review."*

Renewable and Sustainable Energy Reviews 14 (1): 217–32.

16. *J. Kuberan and N. Alagumurthi: Performance and Emission Characteristics of Algae Bio-fuelled Diesel Engine, Int. J. Chem. Sci.: 14(4), 2016.*
17. *Ramachandra, T. V., M. Durga Madhab, S. Shilpi, N. V. Joshi. 2013. "Algal biofuel from urban wastewater in India: scope and challenges." Renew. Sustain. Energy Review; 21: 767–77.*
18. *R. Velappan et al., Investigation of Single Cylinder Diesel Engine using Biodiesel from Marine Algae, IJISTE, 1(4) (2014).*
19. *Kanyaphorn Chaiwong and Tanogkiatkiatsiriroet, Characterisations of Bio-Oil and Bio-Char Products from Algae with Slow and Fast Pyrolysis, IJEE, 10(1), 65-67.*
20. *Ponnusamy, S., H. K. Reddy, T. Muppaneni, C. M. Downes, and S. Deng. 2014. "Life cycle assessment of biodiesel production from algal bio-crude oils extracted under subcritical water conditions." Bioresource Technology 170: 454–61.*
21. *Rao, P. V., & Rao, B. A. (2018). Heat release rate, performance and vibration analysis of diesel engine operating with biodiesel-Triacetin additive blend fuels. International Journal of Automobile Engineering Research and Development, 8(2), 1-12.*
22. *T. Varghese, J. Raj, E. Raja and C. Thamotharan, Performance and Emission Testing on Algae Bio-fuel using Additives, IJEAT, 4(5) (2015).*
23. *G. Nagane and C. Choudhari, Emission Characteristics of Diesel Engine Fueled with Algae Biodiesel –Diesel Blends, IRJET, 2(4) (2015).*
24. *Nagarajan, S., S. K. Chou, S. Cao, C. Wu, and Z. Zhou. 2013. "An updated comprehensive techno-economic analysis of algae biodiesel." Bioresource Technology: 145: 150–6.*
25. *J. Jayaprabakar, A. Karthikeyan, Aashwin Josiah and Anushajan, Experimental Investigation on the Performance and Emission Characteristics of a CI Engine with Rice Bran and Micro Algae Biodiesel Blends, JCHPS Special Issue, 7 (2015).*
26. *R. Velappan, S. Sivaprakasam and M. Kannan, Study the Performance of Algae Oil in Diesel Engine with Various Injection Pressure, IRJET, 2 (5) (2015).*
27. *Sanjay Singh, Experimental Investigation on Performance of Pre-Mixed Charge Compression Ignition Engine, IJISRT, 4 (8) (2019)*

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